ISSN 0202-2893, Gravitation and Cosmology, 2018, Vol. 24, No. 1, pp. 103–111. © Pleiades Publishing, Ltd., 2018.

Late-Time Power-Law Stages of Cosmological Evolution in Teleparallel Gravity with Nonminimal Coupling

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Received April 23, 2017; in final form, November 20, 2017

Abstract—We investigate the Universe evolution at late-time stages in models of teleparallel gravity with power-law nonminimal coupling and a decreasing power-law potential of the scalar field ϕ. New asymptotic solutions are found analytically for these models in vacuum and with a perfect fluid. Applying numerical integration, we show that the cosmological evolution leads to these solutions for some region of the initial conditions, and these asymptotic regimes are stable with respect to homogeneous variations of the initial data. The physical sense of the results is discussed.

DOI: 10.1134/S0202289318010139

1. INTRODUCTION

Final stages of cosmological evolution are studied widely both in General Relativity (GR) as in its modifications. It is interesting and urgent especially due to the need for an explanation of observational data [1–5] (see also the review [6]) indicating the late-time accelerated expansion of the Universe. Realistic models should describe observations and be free of shortcomings. There are such problems as "fine tuning" of initial conditions for realization of the late-time cosmic acceleration in models of ΛCDM [7] and quintessence [8] based on GR, future singularities like a Big Rip, "sudden" and others (see, e.g., [9, 10]). Cosmological evolution leads to a Big Rip in some models of modified gravity [11–15].

There is an alternative formulation of GR, teleparallel gravity (Teleparallel Equivalent of General Relativity, TEGR [16]). It is based, firstly, on Einstein's idea of absolute parallelism [17, 18], that is on using a field of orthonormal bases—tetrads—for tangent space-times and, secondly, TEGR applies the Weitzenböck connection [19] instead of the Levi-Civita one, which leads to zero curvature and nonzero torsion. The TEGR Lagrangian contains the torsion scalar T, and the equations of motion of this theory coincide exactly with those of GR [20–23]. However, modifications of teleparallel gravity (for example, $f(T)$ theory [24–27], and scalar-torsion gravity [28–37] are not equivalents of similar modifications of GR, their difference consists in a term with the divergence of torsion in the Lagrangian (see [38]). It gives rise to different field equations and consequently to a new cosmological dynamics. Therefore, it is of interest to investigate modifications of teleparallel gravity. Scenarios with the late-time cosmic acceleration were already found, for example, in teleparallel gravity with nonminimal coupling of the form $\xi T\phi^2$ [28–32].

In our recent papers [39, 40], stable asymptotic solutions (attractors of the corresponding dynamical systems) were obtained in models of teleparallel gravity with a nonminimal coupling of the form $\xi T\phi^N$ for $N = 2$ and a potential of the scalar field $V(\phi) = V_0\phi^n$. Those methods of dynamical system theory did not allow us to investigate cases of $N > 2$, $\xi > 0$ and $n < 0$. In the present work we shall find the final stages of the Universe evolution in such models which are not studied earlier. Units $\hbar = c = 1$ will be used.

The structure of this paper is as follows. In Section 2 we briefly present the foundations of teleparallel gravity and write the basic equations for the considered models of scalar-torsion gravity. In Section 3, the analytic and numerical results are described. They are discussed in Section 4.

2. BASIC EQUATIONS

Let us shortly present the foundations of teleperallel gravity and write the main equations for its modification with a nonminimally coupled scalar field.

In teleparallel gravity, the dynamical variables are four linearly independent vectors, the tetrad $\mathbf{e}_A(x^\mu) = e^\mu_A\partial_\mu$, where Greek indices are space-time ones, capital Latin indices are tangent space-time ons. A tetrad forms an orthonormal basis in the tangent space at each point of space-time. Then the metric tensor is

$$g_{\mu\nu} = \eta_{AB}e^A_\mu e^B_\nu, \tag{1}$$

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